ALERTNESS AND DROWSINESS DETECTION AND TRACKING SYSTEM

BACKGROUND OF THE INVENTION

This invention relates to systems for determining a subject's state of alertness and drowsiness, and more particularly to apparatus and methods for analyzing EEG signals acquired from a subject to definitively determine the subject's state of alertness, drowsiness, or his or her sleep stage, and to determine whether the subject's performance is impaired thereby.

The Need For Alertness Monitoring, Drowsiness Detection, And Sleep Staging

Sleep deprivation has become one of the most significant causes of error and accident throughout our society. The United States Department of Transportation estimates that 200,000 traffic accidents each year may be fatigue- or sleep-related. In transportation alone, sleep-related accidents annually claim over 5,000 lives, and cause hundreds of thousands of injuries, with an accumulated cost for health care, death, lost productivity, and damage to property in the billions of dollars. U.S. Department of Health and Human Services (1992).

Pilots say their schedules often force them to snooze in the cockpit in order to get enough sleep. Industry insiders report that flight attendants need to periodically check to ensure that the crew is awake. The National Transportation Safety Board (NTSB) cited pilot fatigue as either the cause or a contributing factor in 69 airplane accidents from 1983 through 1986 Stanford Sleep Disorders Clinic and Research Center (1991).

Recent analyses of spectacular accidents and catastrophes suggest that sleepiness may have played an important role in such events, including the Three Mile Island nuclear disaster and the Exxon Valdez oil spill. Mitler et al. (1988). Such accidents endangered large segments of the population and the environment.

The presidential Commission on the Space Shuttle Challenger accident ruled that ground crew fatigue was a contributing cause of the 1986 disaster. In the near catastrophic launch of the shuttle Columbia only three weeks before, operator fatigue was reported as one of the major factors contributing to this incident. Stanford Sleep Disorders Clinic and Research Center (1991). Thus the importance of human vigilance or attention is critical to the performance of individuals in various types of occupations.

Each human being requires a specific amount of sleep in each 24-hour period to maintain a functional level of alertness. If an individual obtains less sleep, he/she will be less alert the following day. Moreover, sleep loss accumulates from one night to the next as a "sleep debt." Therefore, only a modest loss of sleep per night may produce a serious sleep debt when sustained over several nights. The more sleep lost each day, the greater the sleep debt and the larger the impairment. Because individuals often do not recognize that they are sleepy, they seldom guard against involuntary sleep episodes. Much like intoxicated drivers, sleepy drivers do not realize that they are incapable of adequate performance, and may therefore deny drowsiness and impairment U.S. Department. of Health and Human Services (1992).

The effects of sleep loss can be amplified by the bi-modal circadian rhythm. Evidence of this can be found in the temporal patterns of accidents attributed to "falling asleep" or even to mere lapses in operator attention. Studies of single-vehicle truck accidents in Israel, Texas, and New York all reveal two distinct peaks in the time of day when these accidents occurred. Lavie et al. (1986); Langlois et al. (1985); G. W. Duff (unpublished observations). One peak occurs in the early morning hours from 1 a.m. to 7 a.m. and a lower peak occurs during the mid-afternoon from 1 p.m. to 4 p.m.

Another factor which raises risk of accidents is the increasing level of automation. For example, drivers using cruise control and pilots using automatic flight control systems are more susceptible to drowsiness due to the removal of stimulating influences. The Exxon Valdez was on automatic pilot during the critical minutes leading to its grounding as it hit Bligh Reef at 12:04 a.m. Stanford Sleep Disorders Clinic and Research Center (1991). The NTSB's investigation of the accident indicated that the third mate was asleep on his feet and failed to respond to the warning light and alarm identifying the reef U.S. Department. of Health and Human Services (1992). Although automation has provided tremendous benefits, it tends to limit operator activity to vigilant monitoring of the system. Over a period of time, this can reduce the awareness level of the operators and impair their ability to react properly to an external stimulus. In addition, vigilance is further degraded by sleep loss-and fatigue.

Thus, it would be highly desirable to produce an automated real-time system to track the changes in levels of alertness, such as the transition from alertness to drowsiness, or the onset of sleep. In addition, there are a number of other applications in which an automated system for measuring an individual's alertness, drowsiness, or stage of sleep would be highly useful. For example, sleep staging—i.e., the identification of a subject's stage or condition of sleep based on physiological indicators—is used clinically for diagnosing and treating sleep disorders. Sleep staging is also of interest in medical research. Normally, sleep staging is performed by a highly trained physician or technician by studying voluminous EEG records collected while a subject sleeps. A totally automated system for sleep staging could improve consistency and reduce research and treatment costs. Although the sleep scoring field is well established, the greatest disagreement among sleep scorers analyzing identical segments of sleep data occurs when scoring the transition from "stage W" (a state of wakefulness) to "stage 1" sleep (an initial stage of sleep sometimes referred to as the sleep onset period).

No system is currently available which can effectively use the EEG signal for continuous drowsiness tracking and detection. A recent report to the United States Department of Transportation (DOT) surveying methods of drowsiness detection acknowledged that automated processing of the EEG signal has proved very difficult to implement. Wierwille (1994). Various phases or stages of sleep are identifiable using automated methods. However, drowsiness and the onset of sleep are much less distinguishable in the EEG waveform, and therefore, much more difficult to identify using automated methods, than are sleep stages. Research surveyed in the DOT report suggests using a manual method of analyzing EEG and EOG signals. Wierwille (1994), citing Planque (1991).

It should be noted that in many real-world applications, it is insufficient to detect sleep, as normally understood, because it is often essential to provide a warning before an individual's performance is impaired. In particular, for critical applications in which a lack of vigilance could affect health and safety it is necessary to detect extreme sleepiness. "Extreme sleepiness" is used herein to refer to the state during which sleep is perceived as difficult to resist, the individual struggles against sleep, performance lapses occur, and sleep will eventually ensue but has not yet occurred. By